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Applicants: Dixon et al.	)	I hereby certify that this paper (or fee) is being deposited with the United States Postal Service, first class postage prepaid, addressed to: Commissioner for Patents, Washington, DC 20231.
Serial No.: 09/875,619	)	
Filed: June 6, 2001	)	
For: DROPLET DEPOSITION APPARATUS	)	August 31, 2001
Group Art Unit: To be assigned	)	
Examiner: To be assigned	)	James P. Zeller James P. Zeller Reg. No. 28,491

SUBMISSION OF PRIORITY DOCUMENT

Commissioner for Patents
Washington, DC 20231

Sir:

Submitted herewith is a certified copy of Great Britain 9828476.3 filed December 24, 1998, the priority of which is claimed under 35 U.S.C. § 119.

Respectfully submitted,

MARSHALL, GERSTEIN & BORUN

August 31, 2001

By James P. Zeller
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I also certify that the attached copy of the request for grant of a Patent (Form 1/77) bears an amendment, effected by this office, following a request by the applicant and agreed to by the Comptroller-General.

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1. Your reference	~~X280~~ MCM/21720	
2. Patent application number *(The Patent Office will fill in this part)*	9828476.3	24 DEC 1998
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	Xaar Technology Limited Science Park Milton Road Cambridge CB4 0XR	
Patents ADP number *(if you know it)*	7301872001	
If the applicant is a corporate body, give the country/state of its incorporation	UK	
4. Title of the invention	Apparatus for depositing droplets of fluid	
5. Name of your agent *(if you have one)*		
"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	~~Ian Hartwell~~ ~~Xaar Technology Limited~~ ~~Science Park~~ ~~Milton Road~~ ~~Cambridge~~ ~~CB4 0XR~~	Mathys + Squire 100 Grays Inn Rd London WC1X 8AL.
Patents ADP number *(if you know it)*	6631~~840002~~ 1081001	

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7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	Number of earlier application	Date of filing *(day / month / year)*
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11. I/We request the grant of a patent on the basis of this application.

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12. Name and daytime telephone number of person to contact in the United Kingdom Ian Hartwell (01223) 423663

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Apparatus for depositing droplets of fluid

The present invention relates to apparatus for depositing droplets of fluid and comprising an array of fluid chambers, each chamber communicating with an orifice for droplet ejection, with a common fluid inlet manifold and with a common fluid outlet manifold; together with means for generating a fluid flow into said inlet manifold, through each chamber in the array and into said outlet manifold. In particular, the present invention relates to inkjet printheads having such a construction and in which the fluid flow is ink.

Such an inkjet printhead is known from WO91/17051, incorporated herein by reference. Figure 1 of the present application is taken from this document and shows a sectional view taken along the longitudinal axis of a printhead channel 11 formed in a base 12 of piezoelectric material. Ink ejection from the channel is via a nozzle 22 formed in a cover 60, whilst ink is supplied to the channel by means of manifolds 32,33 arranged at either end of the channel. As known, for example from EP-A-0 277 703 and EP-A-0 278 590, piezoelectric actuator walls are formed between successive channels and are actuated by means of electric fields applied between electrodes on opposite sides of each wall so as to deflect transversely in shear mode. The resulting pressure waves generated in the ink cause ejection of a droplet from the nozzle. As is also known, ink may be fed into one and out of the other of the manifolds 32,33 so as to generate ink flow through the channel and past the nozzle during printhead operation. This acts to prevent the accumulation of dust, dried ink or other foreign bodies in the nozzle that would otherwise inhibit ink droplet ejection.

In the course of experiments with such printheads supplied with ink at a rate considered sufficient to prevent foreign bodies from aggregating in the nozzle, it has been discovered that droplet ejection characteristics – particularly the size and speed of the ejected droplets - have varied along the array. It has been established that this variation is a result of a variation in the rest position

of the ink meniscus in each chamber along the array, which is in turn caused by variations in the static pressure at the nozzle in each chamber in the array.

The present inventors have discovered that this variation in pressure is due to the continuous flow of ink, particularly the flow of ink in the manifolds running alongside the array of channels which is equal (at least at the inlet and outlet to the manifolds) to the total ink flow through every channel in the array. Such flow can give rise to significant viscous pressure losses along both inlet and outlet manifolds. This in turn affects the static pressure at the inlet and outlet to each chamber and hence the static pressure at the nozzle of the chamber.

A first aspect of the present invention seeks to solve this hitherto unrecognised problem and consists in apparatus for depositing droplets of fluid and comprising an array of fluid chambers, each chamber communicating with an orifice for droplet ejection, a common fluid inlet manifold and a common fluid outlet manifold; means for generating a fluid flow into said inlet manifold, through each chamber in the array and into said outlet manifold, said fluid flow through each chamber being substantially constant and sufficient to prevent foreign bodies in the fluid from lodging in the orifice; each chamber being further associated with means for effecting droplet ejection from said orifice simultaneously with said fluid flow through each chamber; the inlet manifold having a resistance to flow less than that which would give rise to a variation in static pressure between the inlets to any two chambers in the array sufficient to produce significant differences in droplet ejection properties between said two chambers in the array.

Reducing the flow resistance of the inlet manifold to below a threshold, in accordance with the invention, ensures that any viscous pressure losses that do occur as a result of ink circulation do not adversely affect the uniformity of droplet ejection characteristics over the width of the array. As a result, a uniform image quality across the printed width of the substrate is guaranteed.

A similar advantage is obtained by a second aspect of the invention, according to which an apparatus for depositing droplets of fluid comprises an array of fluid chambers, each chamber communicating with an orifice for droplet ejection, a common fluid inlet manifold and a common fluid outlet manifold; means for generating a fluid flow into said inlet manifold, through each chamber in the array and into said outlet manifold; said fluid flow through each chamber being substantially constant and sufficient to prevent foreign bodies in the fluid from lodging in the orifice; each chamber being further associated with means for effecting droplet ejection from said orifice simultaneously with said fluid flow through each chamber; the resistance to flow of said outlet manifold being chosen such that the pressure at the inlet to any chamber in the array varies between any two chambers by an amount less than that which would give rise to significant differences in droplet ejection properties between said two chambers in the array.

Preferably, apparatus according to the present invention comprises both aspects described above, namely it comprises an array of fluid chambers, each chamber communicating with an orifice for droplet ejection, a common fluid inlet manifold and a common fluid outlet manifold; means for generating a fluid flow into said inlet manifold, through each chamber in the array and into said outlet manifold, said fluid flow through each chamber being substantially constant and sufficient to prevent foreign bodies in the fluid from lodging in the orifice; each chamber being further associated with means for effecting droplet ejection from said orifice simultaneously with said fluid flow through each chamber; the resistance to flow of said inlet and outlet manifolds being chosen such that the pressure at the orifice of a chamber in the array varies between any two chambers by an amount less than that which would give rise to significant differences in droplet ejection properties between said two chambers in the array.

Since the pressure at a chamber nozzle is influenced by the static pressure at both the inlet and outlet to the chamber (it will generally lie midway between the two, neglecting any difference between the flow in and flow out of the

chamber due to droplet ejection), reducing the flow resistance of both manifolds to below appropriate threshold values will ensure that neither inlet nor outlet pressure varies in such a way as to cause significant pressure differences between the nozzles of successive chambers in the array. Variation in image quality over the width of the printhead is thereby reduced to such a level as to be insignificant.

A fourth aspect of the invention addresses the additional complications that arise when a droplet deposition apparatus of the kind discussed above is mounted such that the array direction of the chambers is not horizontal, e.g. vertical. There is comprised in the fourth aspect an apparatus for depositing droplets of fluid and comprising an array of droplet fluid chambers arranged at a non-zero angle to the horizontal, each chamber being supplied with droplet fluid from a common fluid manifold extending parallel to the array; means for generating a substantially constant fluid flow into each chamber of the array; wherein the properties of the manifold vary in a direction lying parallel to the array in such a way as to substantially match the rate of pressure loss along the manifold due to viscous losses in the manifold to the rate of increase of static pressure along the manifold due to the non-horizontal orientation of the manifold.

As a result, image quality remains uniform over the whole height of the chamber array in spite of a difference in head of ink between the top and bottom chambers of the array that may be as great as 12.6 inches (in the case of a vertical printhead for printing an A3-size substrate).

In apparatus of the kind described above, ink is typically supplied from a reservoir arranged above the printhead and flows to a reservoir arranged below the printhead, from where it is returned to the upper reservoir by means of a pump. When the printhead is idle and the pump is switched off, ink drains from the upper reservoir into the lower reservoir via the printhead (and, sometimes, the pump) such that when the printhead is re-activated, the ink

level in the upper tank must be re-established before printing can commence. This can take some time, depending on the size of the pump.

A fifth aspect of the present invention has as an objective the elimination of this waiting period. Accordingly, it consists in droplet deposition apparatus comprising at least one droplet fluid chamber communicating with a first fluid reservoir located above the chamber and with a second fluid reservoir located below the chamber; pump means for conveying fluid from the second fluid reservoir to the first fluid reservoir; and means for preventing the flow of fluid from the first to the second reservoir when said pump means is not operating.

The present inventors have established that in ink supply systems of the kind described above and in which the reservoirs are open to atmosphere, control of the fluid level in each reservoir is critical to operation of the printhead. The upper reservoir is generally chosen so as to provide sufficient static pressure to overcome the viscous resistance to ink flow in the section of the chamber between the chamber inlet and the orifice. At the same time, it must not be so great that the pressure at the nozzle overcomes the surface tension of the ink meniscus and causes ink to "weep" from the nozzle – indeed, a slightly negative pressure at the nozzle is to be preferred. The lower reservoir must similarly exert sufficient negative pressure at the chamber outlet to ensure ink flow. However, as with the upper reservoir, the negative pressure exerted must not be so great as to break the ink meniscus in the nozzle.

These conditions are reliably achieved by a sixth aspect of the invention, according to which there is a droplet deposition apparatus comprising at least one droplet fluid chamber communicating with a first fluid reservoir located above the chamber and with a second fluid reservoir located below the chamber; pump means for conveying fluid from the second fluid reservoir to the first fluid reservoir; and control means for controlling said pump in dependence on the fluid level in said first fluid reservoir.

An alternative aspect of the invention directed to the same problem consists in a droplet deposition apparatus comprising at least one droplet fluid chamber communicating with a first fluid reservoir located above the chamber and with a second fluid reservoir located below the chamber; pump means for conveying fluid from the second fluid reservoir to the first fluid reservoir; the first reservoir including means for diverting fluid to the second reservoir when the fluid level in said first fluid reservoir exceeds a given level.

Eighth, ninth and tenth aspects of the invention are also directed to the same problem but concern the lower tank as follows:

Droplet deposition apparatus comprising at least one droplet fluid chamber communicating with a first fluid reservoir located above the chamber and with a second fluid reservoir located below the chamber; pump means for conveying fluid from the second fluid reservoir to the first fluid reservoir; and means for controlling the supply of fluid into said second reservoir in dependence on the fluid level in said second reservoir.

Droplet deposition apparatus comprising at least one droplet fluid chamber communicating with a first fluid reservoir located above the chamber and with a second fluid reservoir located below the chamber; pump means for conveying fluid from the second fluid reservoir to the first fluid reservoir; the first reservoir further communicating with a third reservoir; the second reservoir including means for diverting fluid to the third reservoir when the fluid in said second reservoir exceeds a given level.

Droplet deposition apparatus comprising at least one droplet fluid chamber communicating with a first fluid reservoir located above the chamber and with a second fluid reservoir located below the chamber; pump means for conveying fluid from the second fluid reservoir to the first fluid reservoir; the second reservoir further communicating with a third, sealed reservoir; the apparatus further comprising means for communicating the third reservoir with atmosphere when the fluid in said second reservoir falls below a given level.

Advantageous embodiments of the invention are set out in the description and dependent claims.

The invention will now be described by way of example by reference to the following diagrams, of which:

Figure 2 is a perspective view of a “pagewide” printhead incorporating the first aspect of the invention.

Figure 3 is a perspective view from the rear and the top of the printhead of figure 2.

Figure 4 is a sectional view of the printhead of figures 2 and 3 taken perpendicular to the direction of extension XX of the nozzle rows XX.

Figure 5 is a sectional view taken along a fluid channel of an ink ejection module of the printhead of figure 1.

Figure 6 is a schematic illustration of a printhead according to a fourth aspect of the invention.

Figures 7 and 8 are schematic illustrations of fluid supply systems according to further aspects of the invention and particularly suited for use with printheads of the kind described with regard to figures 1 to 6.

Figure 2 illustrates a first embodiment of a printhead 10 according to the first, second and third aspects of the present invention. The example shown is a "pagewide" device, having two rows of nozzles 20,30 that extend (in the direction indicated by arrow 100) the width of a piece of paper and which allow ink to be deposited across the entire width of a page in a single pass. Ejection of ink from a nozzle is achieved by the application of an electrical signal to actuation means associated with a fluid chamber communicating

with that nozzle, as is known e.g. from EP-A-0 277 703, EP-A-0 278 590 and, more particularly, UK application numbers 9710530 and 9721555 incorporated herein by reference. To simplify manufacture and increase yield, the "pagewide" row(s) of nozzles may be made up of a number of modules, one of which is shown at 40, each module having associated fluid chambers and actuation means and being connected to associated drive circuitry (integrated circuit ("chip") 50) by means e.g. of a flexible circuit 60. Ink supply to and from the printhead is via respective bores (not shown) in endcaps 90.

Figure 3 is a perspective view of the printhead of figure 2 from the rear and with endcaps 90 removed to reveal the supporting structure 200 of the printhead incorporating ink flow passages 210,220,230 extending the width of the printhead. Via a bore in one of the endcaps 90 (omitted from the views of figures 2 and 3), ink enters the printhead and the ink supply passage 220, as shown at 215 in figure 3. As it flows along the passage, it is drawn off into respective ink chambers, as illustrated in figure 4, which is a sectional view of the printhead taken perpendicular to the direction of extension of the nozzle rows. From passage 220, ink flows into first and second parallel rows of ink chambers (indicated at 300 and 310 respectively) via aperture 320 formed in structure 200 (shown shaded). Having flowed through the first and second rows of ink chambers, ink exits via apertures 330 and 340 to join the ink flow along respective first and second ink outlet passages 210,230, as indicated at 235. These join at a common ink outlet (not shown) formed in the endcap and which may be located at the opposite or same end of the printhead to that in which the inlet bore is formed.

To ensure effective cleaning of the chambers by the circulating ink and in particular to ensure that any foreign bodies in the ink, e.g. dirt particles, are likely to go past a nozzle rather than into it, the ink flow rate through a chamber must be high, for example ten times the maximum rate of ink ejection from the channel. This requires a correspondingly high flow rate in the manifolds that feed ink to and from the chamber. In accordance with the present invention, inlet and/or outlet manifolds are of sufficient cross-sectional

area to ensure that, even at such a high rate of ink flow, any pressure losses along the length of the chamber array due to viscous effects are not significant.

As explained above, significant pressure losses in either or both manifolds may result in significant differences in static pressure at the nozzle between different chambers in the array. This in turn may result in differences in the rest position of the ink meniscus between chambers, which will in turn give rise to drop volume and velocity variations between channels. As is well known, these variations will result in print defects which, depending *inter alia* on the image being printed, on whether there is a significant variation between successive chambers in the array or only between chambers at opposite ends of the array, may be noticeable. In the present invention, the properties of the manifolds are chosen so as to avoid such defects.

For example, a printhead of the kind shown in figures 2-4 typically produces 50pl drops which, at a typical maximum ejection frequency of around 6 kHz, corresponds to a maximum flow rate through the nozzle of each chamber of 300 picolitres per second. Multiplied by the 4604 nozzles necessary to provide a pagewide printing width (typically 12.6 inches) at the standard resolution of 360 dots per inch results in a maximum ejection rate from the nozzles of a printhead of around 83 ml per minute.

Further detail of the chambers and nozzles of the particular printhead of the example is given in figure 5, which is a sectional view taken along a fluid chamber of a module 40. The fluid chambers take the form of channels, 11, machined or otherwise formed in a base component 860 of piezoelectric material so as to define piezoelectric channel walls which are subsequently coated with electrodes, thereby to form channel wall actuators, as known e.g. from EP-0-0 277 703. Each channel half is closed along a length 600,610 by respective sections 820,830 of a cover component 620 which is also formed with ports 630,640,650 that communicate with fluid manifolds 210,220,230 respectively. A break in the electrodes at 810 allows the channel walls in

either half of the channel to be operated independently by means of electrical signals applied via electrical inputs (flexible circuits 60).Ink ejection from each channel half is via openings 840,850 that communicate the channel with the opposite surface of the piezoelectric base component to that in which the channel is formed. Nozzles 870,880 for ink ejection are subsequently formed in a nozzle plate 890 attached to the piezoelectric component.

Reliability considerations demand that the rate at which ink is circulated through the printhead needs to substantially greater – up to ten times greater - than the ejection rate: as previously mentioned, this measure helps confine any foreign bodies in the ink to the main ink flow, reducing the likelihood of nozzle blockage. As a result, the total flow rate through the printhead of the example is of the order of 830 ml per minute. Ink ejection from the nozzles (which will vary with the image being printed) will of course reduce in a varying manner the amount the amount of ink flowing out of the printhead as compared with the amount of ink flowing in: however, as has already been seen, this difference is small in comparison with the overall ink circulation rate, so that it is true to say that the fluid flow rate through each chamber is substantially constant.

It will also be evident that the rate of fluid flow along the inlet manifold will decrease with distance along the array (and away from the inlet bore in one of the endcaps 90) as the number of channels remaining to be supplied with fluid decreases. Similarly, the rate of fluid flow in the outlet manifolds will increase as the number of channels exhausting ink into those manifolds increases with distance along the array.

To accommodate maximum flow rates in both inlet and outlet manifolds without causing significant variations in the image quality printed by different channels in the array, the inlet and outlet manifolds of the example given have cross-sectional areas of 1.6×10^{-4} m^2 and 1.2×10^{-4} m^2 respectively. This typically gives a total pressure drop over the length of inlet manifold of the order of 136 Pa (the surface roughness of the manifolds has little effect, the

flow being laminar). The corresponding pressure drop over the length of each of the outlet manifolds is typically of the order of 161 Pa.

As indicated above, the maximum flow rate – and thus the maximum pressure drop – occurs at the inlet and outlet connections of the inlet and outlet manifolds respectively. In the example given, the pressure drops at these locations also did not exceed that level at which differences in the image quality between successive channels became significant.

A further advantageous characteristic of the configuration of figures 2-4 is the substantially rectangular cross-section of the manifolds which allows the sufficient flow area outlined above to be achieved, but not at the expense of making the printhead wider in the substrate travel direction (perpendicular to both the droplet ejection direction and the channel array direction).

Figure 6 schematically illustrates a further aspect of the invention which applies, as illustrated, to printheads in which the linear array of droplet fluid chambers is arranged at a non-zero angle to the horizontal direction (i.e. at a non-perpendicular angle to the direction of gravity, indicated by arrow X in the figure). For the sake of clarity, only a single linear array of chambers is depicted by arrows 1000. However, the analysis that follows is based on an arrangement of a single inlet manifold 1010 and double outlet manifolds 1020 of the kind shown in figures 2-5. Manifolds 1010,1020 are supplied with and drained of ink at connections 1030 and 1040 respectively.

In the embodiment shown, inserts having a tapered shape are placed in the inlet and outlet manifolds as indicated at 1050 and 1060 such that ink entering the inlet manifold at the top of the array finds that the tapered insert only blocks part of the cross-section of the manifold. As the ink passes down the manifold, some of it flows outwards via the channels 1000 to the outlet manifold 1020 such that, by the time the bottom of the array is reached, there is no ink flowing in the inner manifold and the tapered insert leaves no cross-section for flow. Ink reaching the outlet manifold also flows downwards, via

cross-sections which increase towards the bottom by virtue of further tapered inserts. By the bottom of the array, all the ink (except that which has been ejected for printing) is flowing in the large space allowed by the inserts.

In each manifold, the viscous pressure drop per length down the array is balanced against the gravitational increase in pressure by arranging that the cross-section available for flow at each point is appropriate to the flow there. Taking the length of the array of chambers as L and the nozzle resolution per nozzle row as r, then the total number of nozzles in a two row printhead of the kind shown in figures 2-5 is 2rL and the total ink ejection rate for the printhead is 2rLVf, where V and f are the volume and maximum frequency of droplet ejection respectively. The total flow rate through the printhead, on the other hand, needs to be a factor n – typically 10 – times greater than the ejection rate due to cleaning considerations as mentioned above.

The tapered inserts according to the embodiment of figure 6 cause the flow rate in the inlet manifold to decrease according to the formula 2rVfnx (where x is the distance from the bottom of the array) and that in each outlet manifold to increase according to the formula rVfn(L-x). In combination with manifolds of generally rectangular cross-section, they will also typically give a cross-section available for ink flow at each point along the array that is rectangular, having a large dimension d (perpendicular to the plane of figure 7) and a smaller dimension (W – T(x)) for the inlet manifold and (w-t(x)) for the outlet manifold. Accordingly, the velocity v of the flow in each manifold varies along the array as 2rVfnx/(W-T(x)) for the inlet manifold and as rVfn(L-x)/(w-t(x)) for each of the outlet manifolds.

The pressure drop associated with flow along a tapering non-circular channel is determined by flow velocity v and ink density ρ in accordance with the general equation $K\rho v^2/2$. K is the resistance coefficient f(dx)/D for a short length of pipe dx having a laminar friction factor f =64/(Reynolds Number) and a hydraulic diameter D which, in the case of a rectangular cross-section, is

approximately equal to twice the smaller dimension i.e. 2(W-T(x)) for the inlet manifold and 2(w-t(x)) for the outlet manifold.

In accordance with this aspect of the invention, the viscous pressure drop over a short element of length dx precisely balances the increase in static head due to gravity over that length and equal to $\rho g(dx)$, :g being the acceleration due to gravity. Applying this balance to the expressions for viscous loss given above yields expressions for the variation in manifold dimension necessary to achieve such balance, namely:

$$(W-T)^3 = 16nrfVx\mu/\rho gd$$

for the inlet manifold, and

$$(w-t)^3 = 8nrfV(L-x)\mu/\rho gd$$

for each of the outlet manifolds. This in turn requires that the insert in the inlet manifold has to taper in such a way as to leave a width of passageway for the ink which varies as $x^{1/3}$ whilst the insert in the outlet manifold has to taper in a similar way but from the opposite end of the array. Exactly this variation may be difficult to achieve in practice, particularly if the insert is to be machined, in which case the an approximate variation obtained e.g. by a series of shims may prove acceptable.

Typical figures for a printhead of the kind shown in figures 2-4 and discussed with regard to the first, second and third aspects of the invention are (W-T) =1.46mm at the inlet (connection 1030 to ink supply) end of the inlet manifold 1010 and, similarly, (w-t)= 1.16mm at the outlet (connection 1040 to ink drain) end of each of the outlet manifolds 1020. These figures assume a manifold depth, d, of 40mm, an ink density, ρ, of 900 kg/m^3 and an ink viscosity, μ, of 0.01 Pa.s. They also consider the flow through the channels to be substantially constant, neglecting any difference in flow between the two manifolds due to ink ejection.

The above invention allows, with appropriate adaptation of the manifolds, uniform ejection characteristics to be obtained across the array of a printhead arranged at any angle to the horizontal. It is not restricted to "pagewide" designs, although the potential for a large variation in static pressure across the array that would result were the present invention or alternative measures not employed, is particularly great in such printheads.

It should be noted that whilst variation of flow resistance has been achieved in the example by means of a variation in flow area, this is not the only mechanism available. Others of the parameters mentioned above, in particular the resistance coefficient K, can be varied e.g. by baffles in the manifold, by a variable roughness coating in the manifold. Furthermore, the concept may be employed more than once in a single array - the channels may be separated into two groups, as is known e.g. from WO97/04963, each of which has its own ink circulation system. The invention is also not restricted to systems employing ink circulation - a substantially constant flow of ink would also result from the situation where substantially all of the ink chambers were ejecting ink substantially all of the time.

Referring now to figure 8, there is depicted in a schematic fashion an ink supply system 2000 suitable for use with a through-flow printhead 2010 of the kind discussed above and incorporating a number of aspects of the present invention. Whilst printhead 2010 is shown with the channel array lying horizontal and the nozzles directed for downward ejection as indicated at 2020, it should be noted that the system is equally applicable to non-horizontal arrangements as discussed above.

Ink enters the central inlet manifold 2030 of the printhead from an upper reservoir 2040 open to the atmosphere via air filter 2041 and itself supplied with ink from a lower reservoir 2050 by means of a pump 2060. In accordance with an aspect of the present invention, pump 2060 is controlled by a sensor 2070 in the upper reservoir in such a manner as to maintain the fluid level

2080 therein a constant height Hu above the plane P of the nozzles. A restrictor 2090 prevents excessive flow rate, so that the cycling of the pump does not disturb the pressures established by the free surface 2080. A filter 2095 traps any foreign bodies that may have entered the ink supply, typically via the storage tank. A printhead of the kind discussed above and firing droplets of around 50pl volume generally requires a filter that will trap particles of size 8μm and above in order that these do not block the printhead nozzles which typically have a minimum (outlet) diameter of around 25μm. Smaller drops, e.g. for use in so-called "multipulse" printing, will require correspondingly smaller nozzles (typically 20μm diameter) and greater filtration.

In the lower reservoir 2050, the fluid level 3000 is maintained at a constant height HL below the nozzle plane P by a sensor 3010 which controls a pump 3030 connected to an ink storage tank (not shown). Filter 3020 and restrictor 3040 serve the same purpose as in the upper reservoir. Lower reservoir 2050 is connected to the outlet manifolds 2035 of the printhead.

As explained earlier, the positive pressure applied by the upper reservoir to the printhead inlet manifold together with the negative pressure applied by the lower reservoir to the printhead outlet manifold generates flow through the fluid chambers of the array sufficient to prevent accumulation of dirt without inappropriate pressures at the nozzles. In the example shown, utilising a printhead having the dimensions described above, values of around 280mm for Hu and 320mm for HL have been found to give a pressure at the nozzles of around –200 Pa. A slightly negative pressure of this kind ensures that the ink meniscus does not break, even when subject to mild positive pressure pulses that are typically generated during the operation of such heads (e.g. by the movement of ink supply tubes, vibration from the paper feed mechanism and the ink supply pumps, etc.). Means for controlling the various supply pumps to maintain the free surface levels in the reservoirs substantially constant contributes to such operation.

In accordance with an aspect of the present invention, valves 3050, 3060 are arranged in the ink supply lines to and from the printhead. Electrically connected to the printhead controller along with pumps 2060, 3030 and sensors 2070, 3010, they remain open during printhead operation but close when the printhead is shut off so as to prevent ink draining from the upper reservoir back to the lower reservoir. As a result, printing can be rapidly resumed when the printhead is next switched on. A non-return valve 3070 may also be installed in the supply line to pump 2060 where this is not of the positive displacement kind.

Figure 9 illustrates an alternative ink supply arrangement to that of figure 8. Control circuitry is simplified by allowing the pump 2060 to run continuously, ink flowing back to the lower reservoir when the fluid level in the reservoir exceeds the level of a weir 4000. An air-tight ink storage tank 4010 is mounted above the lower reservoir 2050 and connected thereto by a supply pipe 4020. A further pipe 4030 has one end communicating with the air space 4040 above the ink in the storage tank and another end located at the height of desired ink level A in the lower reservoir such that, when the actual ink level 3000 in the lower reservoir sinks below the desired level A, the end of pipe 4030 is uncovered, allowing air to flow into air space 4040 which in turn allows more ink to flow out of the tank via tube 4020 and into the lower reservoir 2050, thereby restoring the ink level to its desired value. As with the arrangement of figure 8, normally closed valves and non-return valves can be employed to ensure quick start up of printing after periods of non-use.

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Claims

1. Apparatus for depositing droplets of fluid and comprising an array of fluid chambers,
each chamber communicating with an orifice for droplet ejection, a common fluid inlet manifold and a common fluid outlet manifold;
means for generating a fluid flow into said inlet manifold, through each chamber in the array and into said outlet manifold,
said fluid flow through each chamber being substantially constant and sufficient to prevent foreign bodies in the fluid from lodging in the orifice;
each chamber being further associated with means for effecting droplet ejection from said orifice simultaneously with said fluid flow through each chamber;
the inlet manifold having a resistance to flow less than that which would give rise to a variation in static pressure between the inlets to any two chambers in the array sufficient to produce significant differences in droplet ejection properties between said two chambers in the array.

2. Apparatus for depositing droplets of fluid comprising
an array of fluid chambers,
each chamber communicating with an orifice for droplet ejection, a common fluid inlet manifold and a common fluid outlet manifold;
means for generating a fluid flow into said inlet manifold, through each chamber in the array and into said outlet manifold,
said fluid flow through each chamber being substantially constant and sufficient to prevent foreign bodies in the fluid from lodging in the orifice;
each chamber being further associated with means for effecting droplet ejection from said orifice simultaneously with said fluid flow through each chamber;
the resistance to flow of said outlet manifold being chosen such that the pressure at the inlet to any chamber in the array varies between any two chambers by an amount less than that which would give rise to significant

differences in droplet ejection properties between said two chambers in the array.

3. Apparatus for depositing droplets of fluid comprising
an array of fluid chambers,
each chamber communicating with an orifice for droplet ejection, a common fluid inlet manifold and a common fluid outlet manifold;
means for generating a fluid flow into said inlet manifold, through each chamber in the array and into said outlet manifold,
said fluid flow through each chamber being substantially constant and sufficient to prevent foreign bodies in the fluid from lodging in the orifice;
each chamber being further associated with means for effecting droplet ejection from said orifice simultaneously with said fluid flow through each chamber;
the resistance to flow of said inlet and outlet manifolds being chosen such that the pressure at the orifice of a chamber in the array varies between any two chambers by an amount less than that which would give rise to significant differences in droplet ejection properties between said two chambers in the array.

4. Apparatus according to any preceding claim, wherein the array of chambers is linear.

5. Apparatus according to any preceding claim, wherein said two chambers are located adjacent one another in the array.

6. Apparatus according to any previous claim, wherein said two chambers are located remote from one another in the array.

7. Apparatus for depositing droplets of fluid and comprising an array of droplet fluid chambers arranged at a non-zero angle to the horizontal, each chamber being supplied with droplet fluid from a common fluid manifold extending parallel to the array;

means for generating a substantially constant fluid flow into each chamber of the array;
wherein the properties of the manifold vary in a direction lying parallel to the array in such a way as to substantially match the rate of pressure loss along the manifold due to viscous losses in the manifold to the rate of increase of static pressure along the manifold due to the non-horizontal orientation of the manifold.

8. Apparatus according to claim 7, wherein the array is arranged substantially vertically.

9. Apparatus according to claim 7 or 8 and including a common fluid outlet manifold for all chambers.

10. Apparatus according to claim 9 and including means for generating a fluid flow into said common fluid manifold, through each chamber in the array and into said common fluid outlet manifold.

11. Droplet deposition apparatus comprising at least one droplet fluid chamber communicating with a first fluid reservoir located above the chamber and with a second fluid reservoir located below the chamber;
pump means for conveying fluid from the second fluid reservoir to the first fluid reservoir; and
means for preventing the flow of fluid from the first to the second reservoir when said pump means is not operating.

12. Droplet deposition apparatus according to claim 11 wherein said chamber comprises a channel connected to said first and second fluid reservoirs at respective ends thereof and to a nozzle for droplet ejection at a point intermediate said first and second ends.

13. Droplet deposition apparatus comprising at least one droplet fluid chamber communicating with a first fluid reservoir located above the chamber and with a second fluid reservoir located below the chamber;
pump means for conveying fluid from the second fluid reservoir to the first fluid reservoir; and
control means for controlling said pump in dependence on the fluid level in said first fluid reservoir.

14. Droplet deposition apparatus comprising at least one droplet fluid chamber communicating with a first fluid reservoir located above the chamber and with a second fluid reservoir located below the chamber;
pump means for conveying fluid from the second fluid reservoir to the first fluid reservoir;
the first reservoir including means for diverting fluid to the second reservoir when the fluid level in said first fluid reservoir exceeds a given level.

15. Droplet deposition apparatus comprising at least one droplet fluid chamber communicating with a first fluid reservoir located above the chamber and with a second fluid reservoir located below the chamber;
pump means for conveying fluid from the second fluid reservoir to the first fluid reservoir; and
means for controlling the supply of fluid into said second reservoir in dependence on the fluid level in said second reservoir.

16. Droplet deposition apparatus comprising at least one droplet fluid chamber communicating with a first fluid reservoir located above the chamber and with a second fluid reservoir located below the chamber;
pump means for conveying fluid from the second fluid reservoir to the first fluid reservoir;
the first reservoir further communicating with a third reservoir; the second reservoir including means for diverting fluid to the third reservoir when the fluid in said second reservoir exceeds a given level.

17. Droplet deposition apparatus comprising at least one droplet fluid chamber communicating with a first fluid reservoir located above the chamber and with a second fluid reservoir located below the chamber;
pump means for conveying fluid from the second fluid reservoir to the first fluid reservoir;
the second reservoir further communicating with a third, sealed reservoir;
the apparatus further comprising means for communicating the third reservoir with atmosphere when the fluid in said second reservoir falls below a given level.

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Fig.1

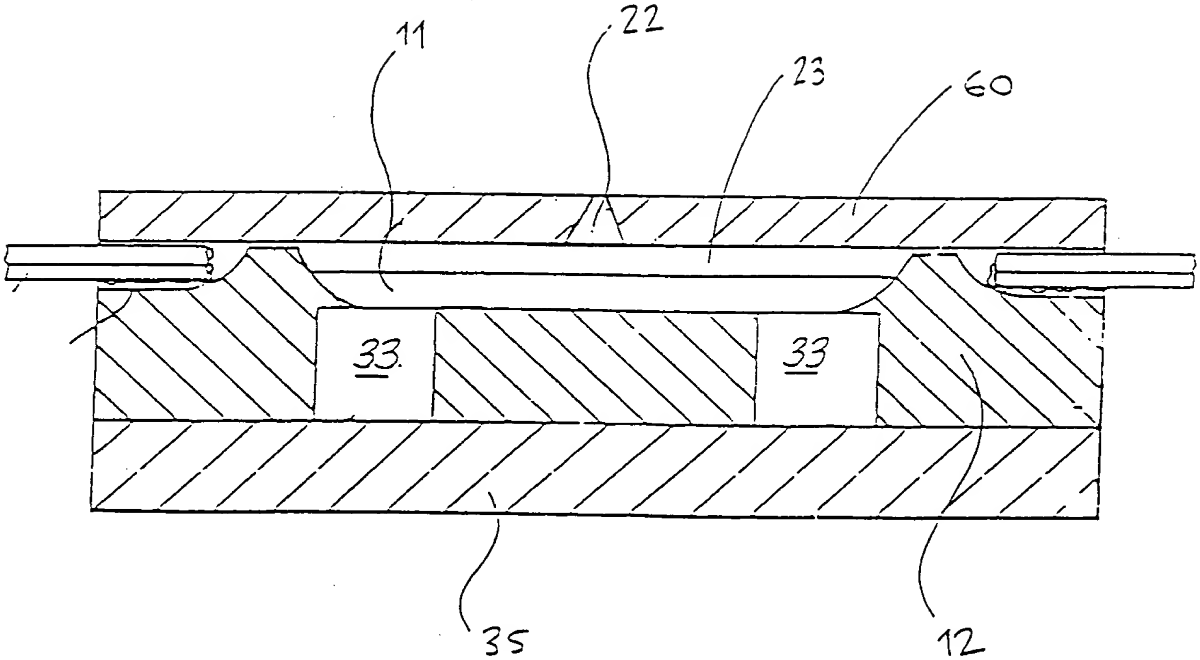

Fig. 2

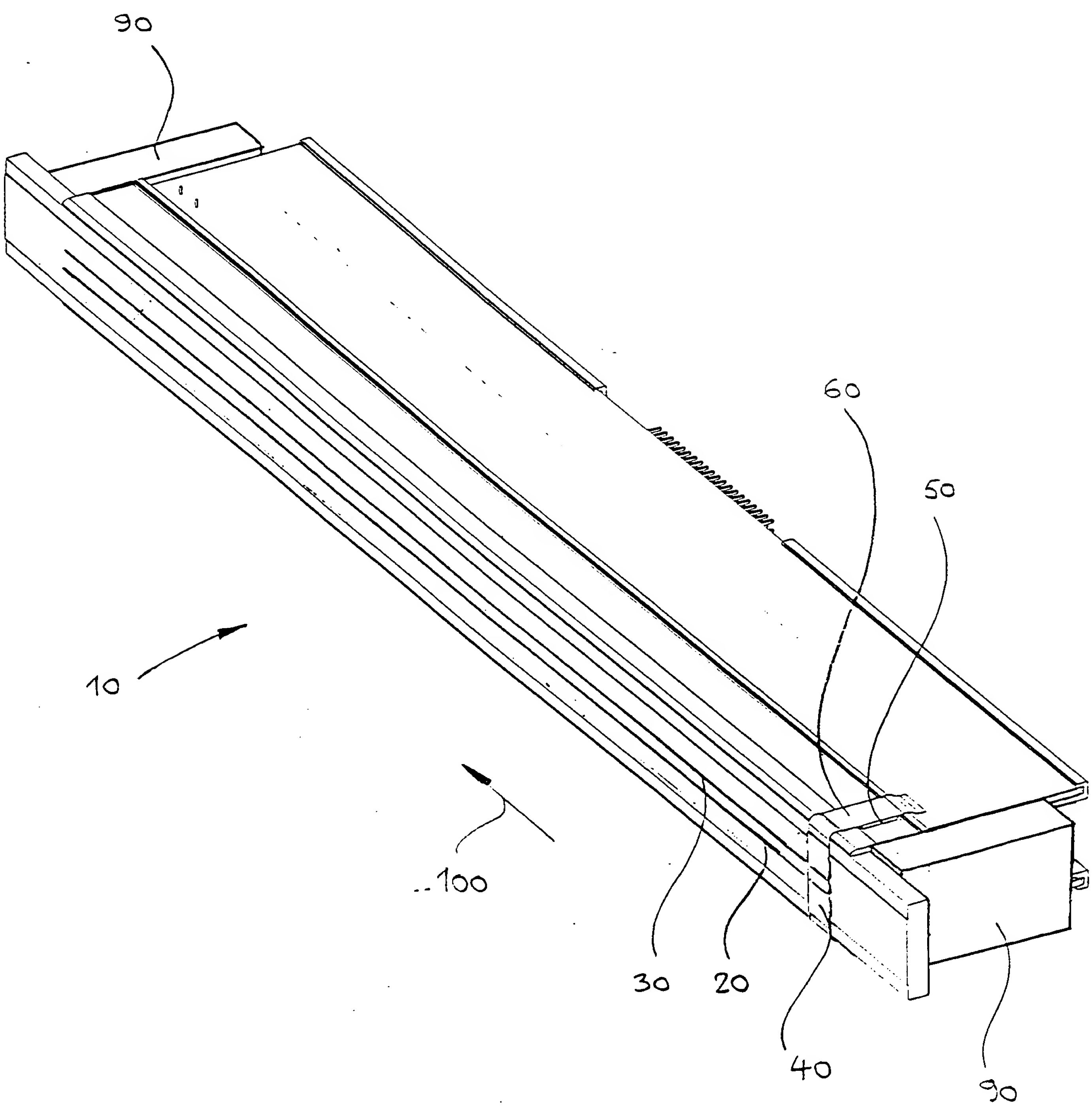

Fig. 3

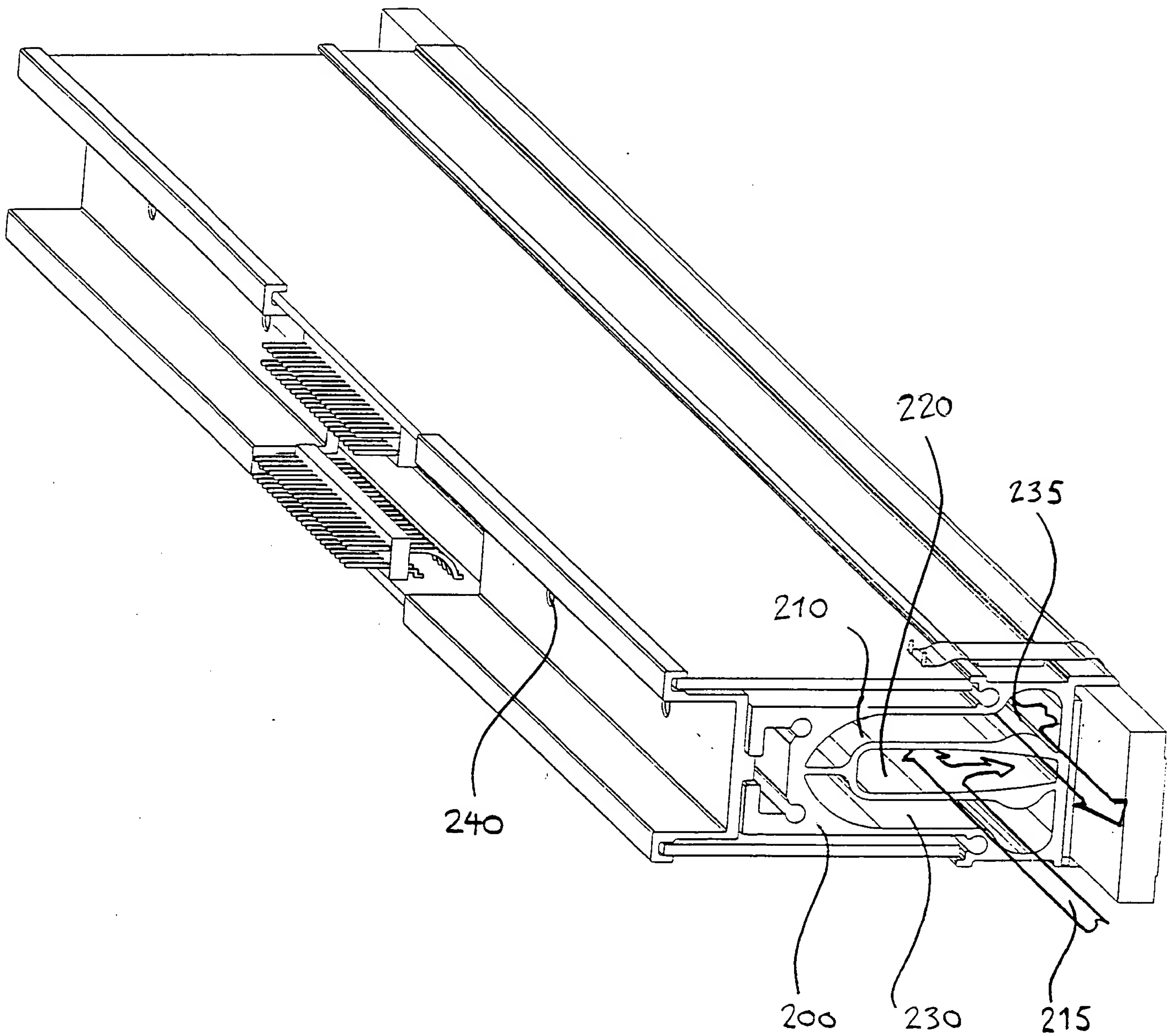

Fig. 4

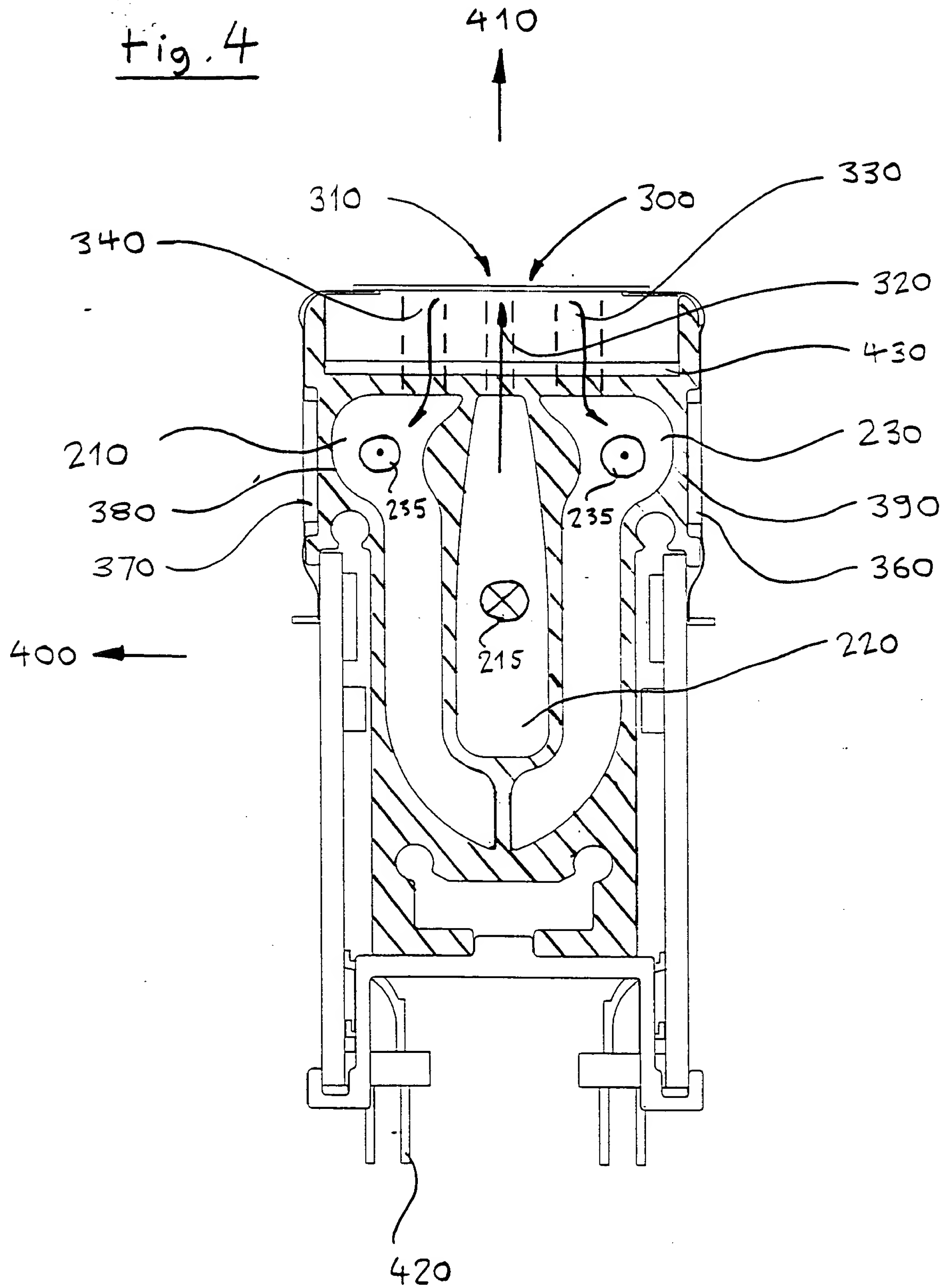

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FIG. 5

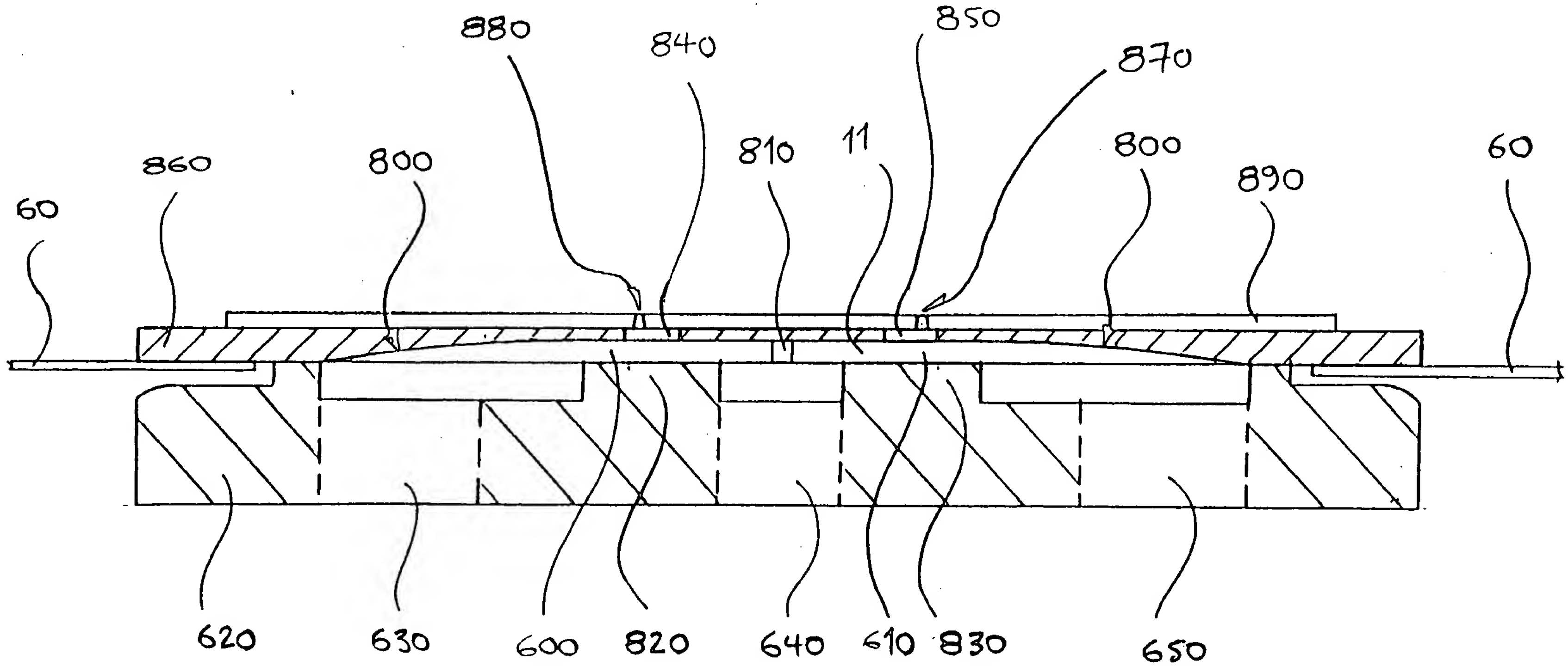
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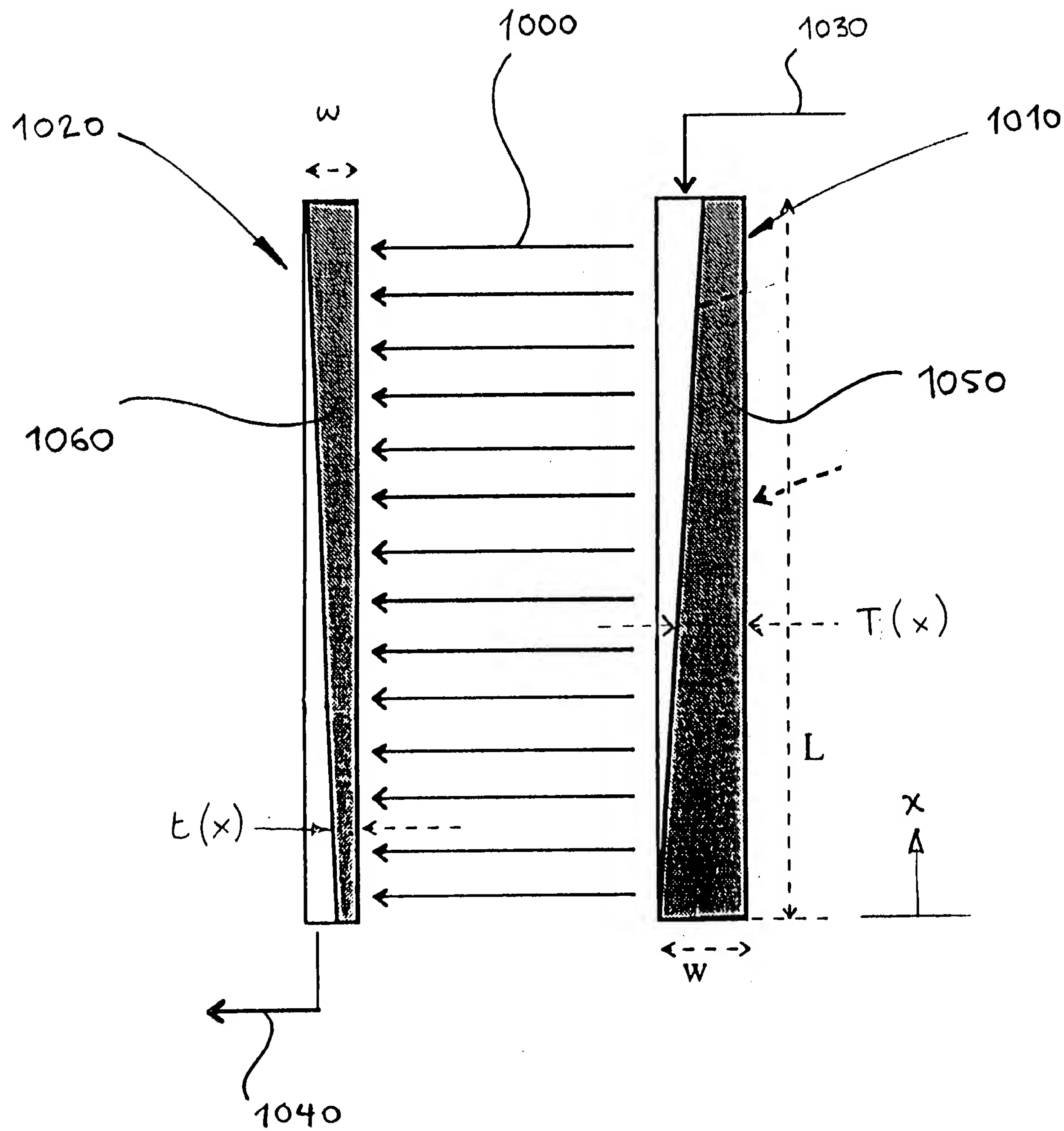
Fig. 6



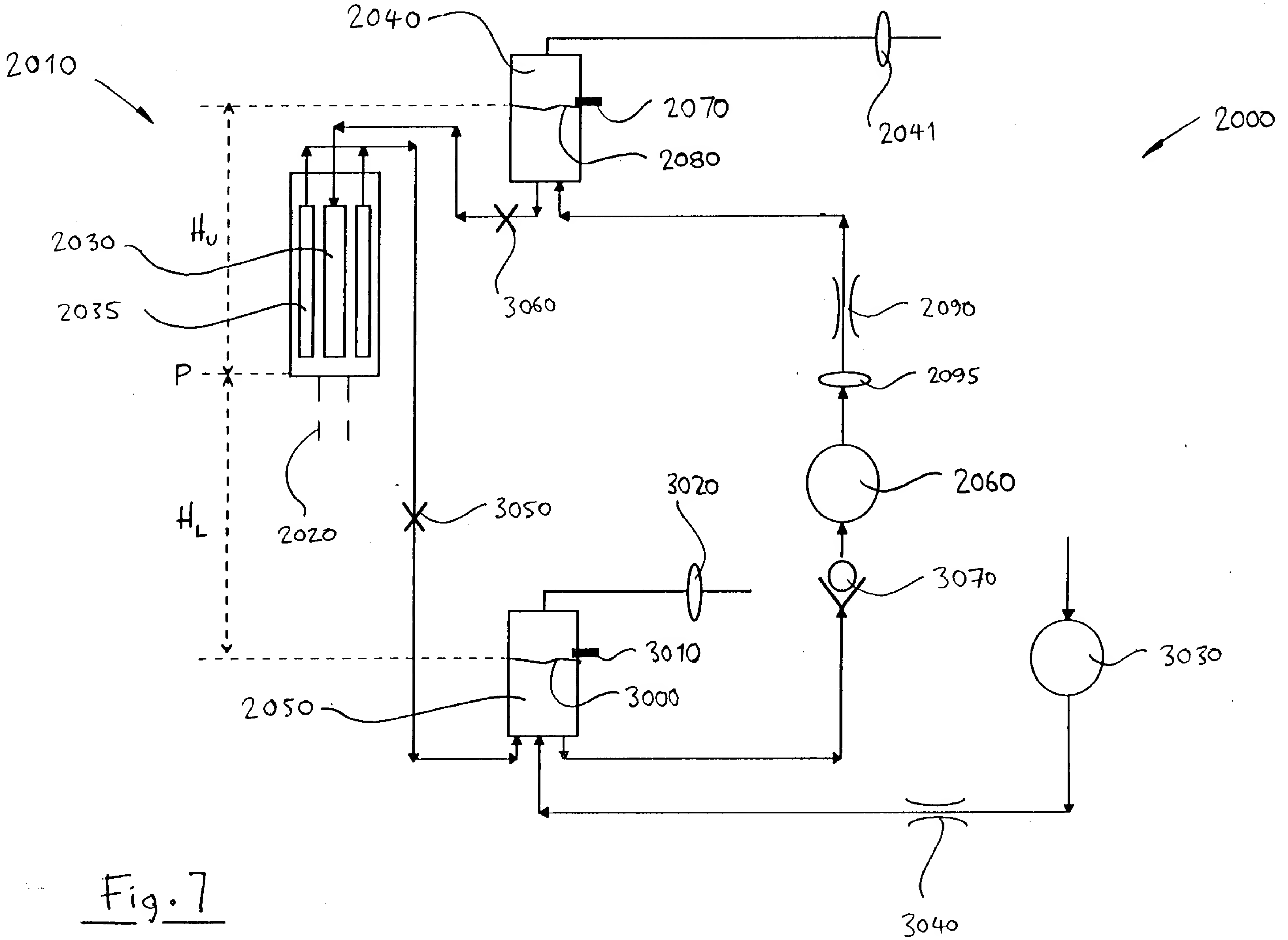

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Fig. 7

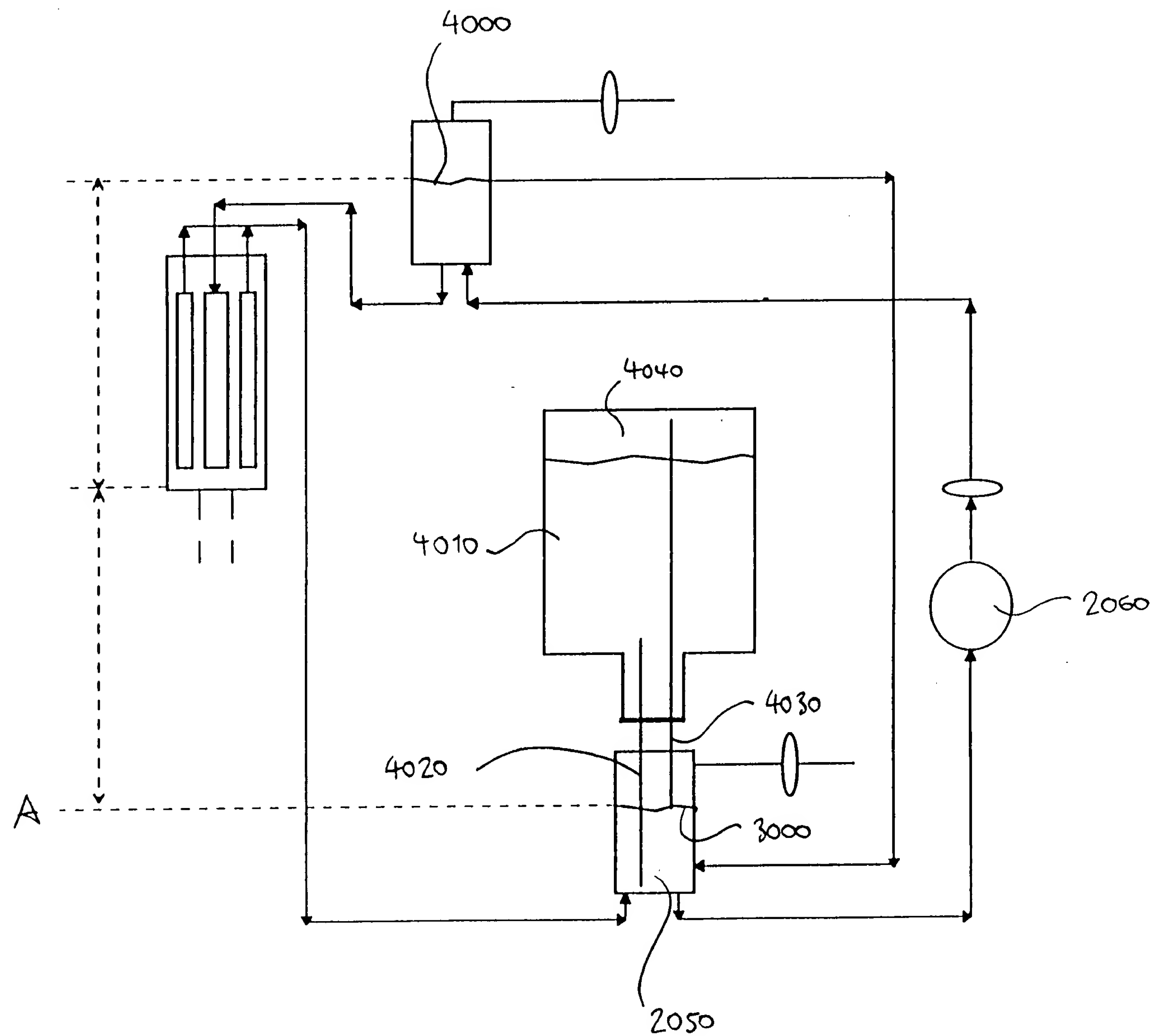

Fig. 8